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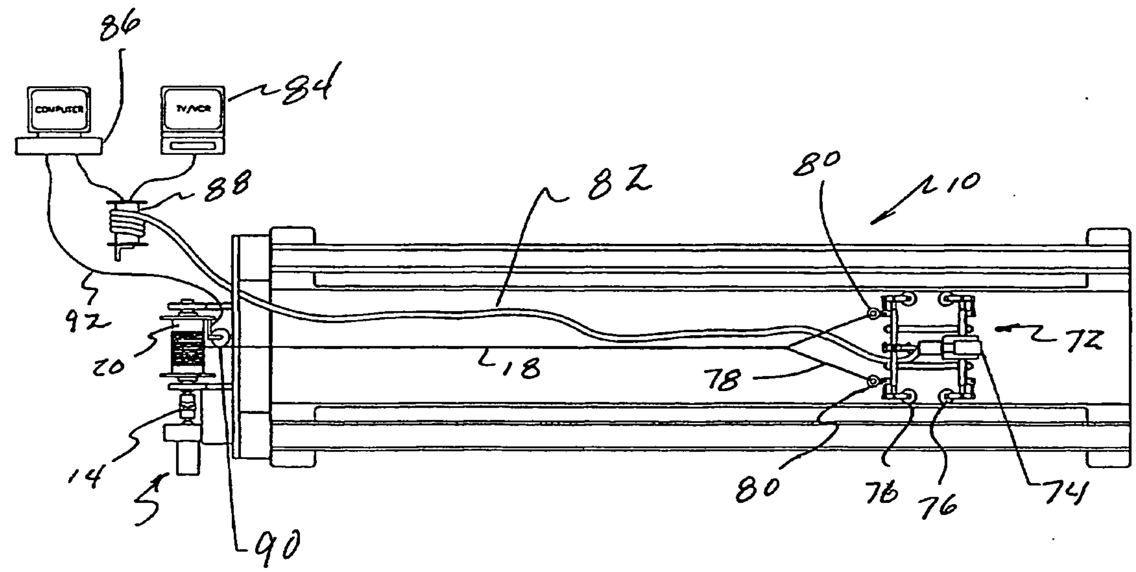

(57) Abstract: A comprehensive system for the cleaning, inspection, and testing of tubulars, particularly riser pipes, is provided. In a first aspect, a method of inspecting a tubular comprises cleaning, visually inspecting, corrosion mapping, and TOFD testing the tubular. In another aspect, a specially designed or adapted tool is provided for each of the steps of the method.

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ULTRASONIC TESTING SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to the field of non-destructive testing and, more particularly, to a method and apparatus for cleaning and inspecting tubulars, including inspecting for flaws in pipe sequentially using pulse echo and time of flight diffraction (TOFD).

BACKGROUND OF THE INVENTION

There has long been a need for methods of cleaning and inspecting tubulars, particularly offshore riser pipe, on site. Typical methods used today include disassembling the riser pipe from a rig, transporting the riser pipe to a yard, and there conducting inspection and testing of the tubular using well known techniques. Such a method is not only expensive and time consuming, but also very disruptive of normal operations on the rig.

Thus, there remain a need for a system and method of inspecting tubulars on site to minimize down time of the rig, and to save the costs of transporting and returning the tubulars under inspection.

Even the techniques used at the yard for the testing and inspection of tubulars have certain drawbacks. Various techniques have been developed to detect flaws in structures, particularly welds in such structures. The ability to detect flaws in structures such as tubulars in drilling and production rigs and pipelines is especially critical before any catastrophic failure occurs.

Ultrasonic testing of metal structures has proved to an effective and practical tool for nondestructive testing (NDT). Known ultrasonic techniques typically yield reliable examination results. However, some geometries make known ultrasonic techniques difficult or even impossible to apply, or yield inaccurate results.

One technique that has gained common acceptance in the NDT field is referred to as the echodynamic technique. This technique consists of measuring the duration of the defect echo in axial or circumferential tube direction when the ultrasonic probe (in pulse-echo mode) is moved over the defect. Such a defect may involve slag, porosity, stress cracking, or other anomalies from the anticipated metal grain structure. In the pulse-echo mode, the depth of a defect is calculated from the probe displacement distance at which a defect echo was picked up. To detect the defect, the amplitude of the defect echo should be above noise level. However, many defects that are of particular concern escape detection if they are oriented in a particular way relative to the applied pulse echo, because this technique relies on the reflectivity of the defect. In fact, the pulse echo technique is used in the present invention for corrosion mapping in determining pipe wall thickness. However, as previously described, the pulse echo technique may miss certain flaws, and this fact has lead to the development of other testing techniques.

The Time of Flight Diffraction technique (TOFD) was developed by the AEA's Harwell Laboratory in Britain in the mid seventies as a method of accurately sizing and monitoring the through-wall height of in-service flaws in the nuclear industry. For weld inspection, it was quickly recognized that the method was equally effective for the detection of flaws, irrespective of type or orientation of the flaw, since TOFD does not rely on the reflectivity of the flaw. Rather, TOFD detects the diffracted sound initiating from the tips of the flaw.

In TOFD, a transmitting probe emits a short burst of sound energy into a material and the sound energy spreads out and propagates in an angular beam. Some of the energy is reflected from the flaw but some of the energy is incident to the flaw and is diffracted away from the flaw. A fraction of this diffracted sound travels toward a receiving probe. The diffracted signals which are received by the receiving probe are time resolved using simple geometry calculations and are graphically displayed in a grey scale form.

While the TOFD technique has proved effective for many geometries, there remains a need for a method and system for detection of flaws from within a cylindrical structure, such as a pipe or riser stanchion. The present invention is believed to be the first structure and method of NDT using TOFD from within a tubular such as a riser pipe.

SUMMARY OF THE INVENTION

The present invention addresses these and other needs in the non-destructive testing art by providing a comprehensive system for the cleaning, inspection, and testing of tubulars, particularly riser pipes. In a first aspect of the present invention, a method of inspecting a tubular comprises cleaning, visually inspecting, corrosion mapping, and TOFD testing the tubular. The present invention is also adapted for use with new construction in which the cleaning step may not be necessary in some cases. In another aspect of the invention, a specially designed or adapted tool is provided for each of the steps of the method.

The step of cleaning the inside of the tubular includes pre-wetting, if desired, to remove loose debris and to soften dried drilling fluids and other materials. An air motor driven wire brush with an alignment tool is then pulled or pushed through the tubular. For small lines, which may include weld material protruding into the cylindrical space, a cutting tool is also provided to precede the wire brush. The wire brush may also be followed by a jet spray of water to wash away cuttings, rust, and dust.

The step of visual inspection comprises moving a camera throughout the tubular. A digital linear placement transducer, referred to as an encoder, is provided to precisely locate the camera within the tubular. The camera provides a video signal to a computer and to a recorder for a permanent record.

The step of corrosion mapping employs a pulse echo system to map wall thickness of the tubular. A drive system is provided to move the tool holding the pulse echo probes through the tubular, and the computer once again makes a record

of the mapping. Finally, a TOFD system is provided to detect flaws in the tubular seam and girth welds, such as in-service defects, stress and fatigue cracking, corrosion, erosion, weld fabrication defects, lack of fusion (LOF), slag porosity, and other defects.

These and other features of the invention will be apparent to those skilled in the art from a review of the following description along with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1a is a side view in partial section of a cleaning system in accordance with this invention for cleaning a large ID pipe, such as a 21" ID main riser pipe.

Figure 1b is an end view of the cleaning system of Figure 1a.

Figure 2 is a side view in partial section of a cleaning system for cleaning smaller ID pipe, such as 3" and 4" pipes.

Figure 3a is a side view in partial section of a system for the visual inspection of the larger diameter pipe.

Figure 3b is an end view of the visual inspection system of Figure 3a.

Figure 4a is a side view in partial section of a system for the visual inspection of small ID pipe, such as for a 3" or 4" nominal ID pipe.

Figure 4b is an end view of the visual inspection system of Figure 4a.

Figure 5a is a side view in partial section of a system for performing corrosion mapping inspection of a large diameter pipe.

Figure 5b is an end view of the system of Figure 5a.

Figure 5c is a side section view of corrosion mapping tool suitable for use in the inspection system of Figures 5a and 5b.

Figure 6a is a side view in partial section of a system for performing corrosion mapping inspection of a small diameter tubular.

Figure 6b is an end view of the system of Figure 6a.

Figures 6c and 6d are side section views of corrosion mapping tools for 3" and 4" nominal ID tubulars, respectively, suitable for use in the system of Figures 6a and 6b.

Figure 7 is a side view in partial section of a preferred system for performing TOFD testing of a large diameter pipe.

Figure 8a is a side view in partial section of a preferred system for performing TOFD testing of a small diameter tubular.

Figures 8b and 8c are side section views of TOFD tools for performing testing of 4" and 3" tubulars, respectively, suitable for use with the system of Figure 8a.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention includes a system for the inspection of tubulars and a method of conducting such an inspection using the system. The system of the invention includes the systems for carrying out the various stages of inspection, as well as the tools which have been designed or specially adapted for the inspection. The method of the invention comprises primarily four steps: (1) cleaning; (2) visual inspection; (3) corrosion mapping; and (4) TOFD inspection. The following description follows through the four steps of the method, with the structure described during each step.

Cleaning

Figures 1 and 1a show the arrangement for cleaning the main, 21" ID riser pipe **10**. At one end of the pipe **10** is coupled a winch assembly **12** driven by a winch motor **14** and the winch assembly **12** is adapted for mounting to a flange **16** of the pipe **10**. A wire line **18** is wound on a winch spool **20**, enough wire line to reach the entire length of the pipe **10**. The end of the wire line **18** terminates in a swivel **22**, which couples to a cleaning tool **24**. As used herein, the term "drawing system" refers to the mechanism for drawing the cleaning tool through the pipe, and includes the winch assembly **12**, the winch motor **14**, and the wire line **18**.

On the opposite end of the pipe **10** is mounted a drive mechanism **26** to actuate the cleaning tool **24**. The drive mechanism **26** includes a motor mount **28** on which is mounted an air motor **30**. The motor mount **28** also includes at least two guide bars **32** which slidingly extend into auxiliary lines **34** and the guide bars are preferably about 3.5 feet long. The air motor **30** is provided with an air supply **36**, which may be any available air supply of about 120 psi. Coupled to the drive shaft of the air motor is a drive tube **38**, which is preferably made up of 3' sections, and the sections of drive tube **38** may be quickly and easily made up with couplings **40**. The end of the drive arm or tube **38** opposite the drive motor **30** is coupled to the cleaning tool **24**. The cleaning tool **24** includes a pair of wire brushes **42** and **44**, separated by a centralizer ring **46**, which maintains the cleaning tool in alignment within the pipe **10** to ensure complete circumferential cleaning of the inside of the pipe. Finally, speed control for the air motor **30** is provided by an air regulator and dryer **48** for complete control of the cleaning operation.

To begin the procedure of cleaning the inside of the main pipe **10**, the inside of the pipe is first flushed, preferably with potable water, to remove loose debris and to pre-wet any dried drilling mud for ease of removal by the cleaning tool **24**. Next, the motor mount **28** is installed by sliding the guide bars into the auxiliary tubes. With the guide bars fully inserted, the position of the air motor can be adjusted to center the axis of rotation of the motor output shaft to account for variations in the positioning of the auxiliary pipes. The mounting assembly is then pulled back out (about 3.5 feet), and the first section of drive tube **38** is installed on the motor drive. This provides sufficient clearance for the cleaning tool **24** on the end of the first section of drive tube **38**. The cleaning tool is then placed inside the end of the main pipe **10**. Next, the air line **36** is connected to the motor and the air regulator **48** is adjusted to zero. The air pressure is then slowly increased until the cleaning tool **24** just starts to turn. Note that due to the coefficient of friction, more air pressure will be required to start turning the tool than is required to keep the tool turning.

The cleaning tool can then be manually run into the pipe for cleaning the first portion. Alternatively, the wire line **18** can be pushed through the pipe **10** and connected to the swivel **22** prior to making up the tool to the air motor. With this setup, the winch motor is used to pull the cleaning tool through the pipe. When the motor mount **28** contacts the end of the pipe, the air supply **36** is shut off, and the mount **28** is pulled back to provide enough clearance to attached another 3' section of drive tube **38**. The procedure is repeated until the entire length of the pipe **10** has been cleaned with the cleaning tool. The process is completed by flushing the pipe with water until the water at the other end of the pipe is clear of debris.

Another setup is required for cleaning the smaller auxiliary pipes. Figure 2 depicts the arrangement for cleaning such smaller diameter 3 and 4 inch nominal ID pipes, which may otherwise be referred to herein as tubulars or lines. These are, for example, a choke and kill line **50** and a mud booster line **52**, respectively. A similar arrangement is used for cleaning both lines, and the cleaning tool comprises a cutting or grinding tool **54** which is used primarily to remove welds which extend down into the lines **50** and **52**. Removing the protruding welds ensures that the inspection tools which are later to be used have room to travel freely through the pipes.

Immediately behind the cutting tool **54** is a wire brush **56** for removing rust and loose debris from the inside of the pipe. Immediately behind the wire brush **56** is a centralizing sleeve **58**, preferably made of a hard plastic or other appropriate material, to align the cutting tool **54** and the wire brush **56**. The cutting tool, wire brush, and centralizing sleeve are all coaxially mounted to a drive shaft **60** which is coupled to an air motor **62** for high speed rotation of the coaxially mounted tools. The air motor **62** is provided with pressurized air from a rig air supply line **64** which is provided with a valve **66** which provides both positive shutoff and speed control by controlling air pressure to the air motor **62**. On a common line with the rig air supply line **64** is a water supply line **68** which provides water under pressure to water jet nozzle **70** which washes rust, dust, and other debris forward through the pipe.

Visual Inspection

Figures 3a and 3b depict a structure for visual inspection of the interior surface of the main pipe **10**. An alternative means for visual inspection uses a camera mounted on a TOFD tool, described below.

The structure of Figure 3a includes a camera carrier **72** on which is mounted a camera **74** having a wide angle lens for complete circumferential viewing of the interior of the pipe. The carrier **72** is retained securely centered within the pipe **10** with a plurality of spring loaded wheels **76**. The carrier with camera mounted thereon is drawn through the pipe with a harness **78** coupled to the carrier with swivel mounts **80**. The harness **78** is joined to the wire line **18** wound onto the winch **20** spool, as previously described.

The camera **74** provides a signal over a signal line **82** to a television and video cassette recorder **84** and a computer **86** to provide real time viewing of the camera view and to provide a record of the visual inspection. The signal line **82** is preferably taken up on a take-up reel **88** to keep the slack out of the signal line **82** during the inspection. As the wire line **18** is taken up by the winch, it passes through a digital linear placement transducer or encoder **90**, which is simply an idler of precisely known diameter so that the position of the carrier **72** along the longitudinal direction of the tubular is known. The encoder **90** is coupled to the computer **86** by a signal line **92**. The encoder may alternatively be mounted to the carrier **72**, and the signal line **92** may then be included with the signal line **82**.

Because of constricted space, a different structure is called for when viewing the interior surface of the smaller lines **34**, as depicted in Figures 4a and 4b. A similar arrangement is provided for the inspection of both 3" and 4" lines. The system of Figures 4a and 4b uses the same mounting for the winch as previously described, but now it can be seen that the winch is rotatable on its mount so that the wire line **18** may be directed onto a line **34**.

The camera **74** is mounted to a centralizer sleeve **94**, which is coupled to the wire line **18** with a swivel mount **96**. The centralizer sleeve adapts the same camera

to different ID auxiliary lines. The signal from the camera **74** is provided over the signal line **82** to the television and recorder **84** and to the computer **86** as previously described. The camera is drawn through the auxiliary line **34** by the wire line, which passes over the encoder **90** so that the longitudinal position of the camera is known at all times. The wire line passes over an idler pulley **98** which presses against the encoder **90**.

The purpose of the visual inspection of the interior surface is to show up any obvious surface cracks or corrosion, and to provide for a more comprehensive ultrasonic inspection to follow. It provides the user with a visual inspection record, through the recorder **84**, of the assembled drilling riser joint internal pipe surfaces, for example, although the system and method of this invention may be applicable to other tubulars.

To use the visual inspection system, the camera is installed to the appropriate size adapter sleeve for the line to be inspected, and the camera cable is fished through the line, starting from the box end to the pin end, for example. The cable is then connected to the camera, and the winch assembly is mounted to the end of the riser pipe. The wire line is coupled to the encoder, and the remaining cable connections are made to the computer and television with recorder. The encoder is zeroed, and the image is viewed on the screen of the television to ensure adequate picture quality. Then, using the winch, the wire line is drawn through the tubular. The user can watch the television while making an inspection record. The procedure should then be repeated for all tubulars to be inspected.

Corrosion Mapping

Figures 5a, 5b, and 5c depict the structure for corrosion mapping of the interior of the main pipe **10**. Figure 5a is a side view of a corrosion mapping tool **100**, constructed in accordance with the invention, positioned within the main pipe **10**. Figure 5b is an end view showing the mounting hardware for moving the tool **100**, and Figure 5c is a detail view of the corrosion mapping tool **100** itself.

Referring first to Figure 5c and the corrosion mapping tool **100**, the tool comprises primarily a truncated cylinder **102** with flanges **104** and **106** at the left and right ends of the cylinder **102**, respectively. The cylinder **102** is axially oriented along an axis **103**, which when in use is coaxial with the axis of the pipe **10**. Mounted to the flange **104** in abutting contact is a seal plate **108** which is retained by an end plate **110**, held to the flange with a set of bolts **112**, for example. One such bolt **112** may be replaced by a lifting eye **114** to assist in transporting the tool **100**, since the tool **100** is roughly 20" in diameter and quite heavy. At the other end of the cylinder **102**, mounted to the flange **106**, is an end plate **116**, a seal plate **118**, and a backing support ring **120**, all held to the flange **106** with a set of bolts **112**, for example.

Note that the mounting hardware for the seal plates **108** and **118** is not the same for each seal plate. The end plate **110** is to the left of the seal plate **108**, *i.e.* away from the flange **104**, and the end plate **116** is to the left of the seal plate **118**, *i.e.* in abutting contact with the flange **106**. This arrangement provides support for the compliant seal plates when the bend under friction against in the inside diameter of the pipe **110** when the tool **100** is drawn through the pipe.

The end plate **116** also provides a mount for a hub **122** held to the end plate **116** with a plurality of bolts **124**, for example. The hub receives a coupling **126**, which receives a water hose connection **128** (see Figure 5a). Water from the water hose connection **128** provides a couplant for the pulse echo signal used in the corrosion mapping as described below. The hub **122** also includes a water channel **130** leading the flow of water to a flexible tube **132** which carries the water to a penetration **134** through the cylinder **102**. Thus, the water floods an annular chamber **135** (See Figure 5a) formed by the cylinder **102**, the seal plates **108** and **118**, and the interior diameter of the main pipe **10**.

The end plate **110** provides a mount for a cable connector **136** which receives a transducer signal cable **138** (See also Figure 5a) to be described below. The transducer signal cable **138** terminates in a pulse echo transducer **140**, which is

mounted in an insert **142** which in turn is installed in the cylinder **102**. It should be understood that although only one transducer is shown, a plurality of transducers are used in order to provide a full 360° coverage to map the entire pipe. The transducer **140** provides a pulse echo signal to determine wall thickness of the cylinder **102** in a manner well known in the art. The cylinder **102** may also provided with a nipple **144** to receive a lifting ring, if desired.

Figures 5a and 5b show the arrangement for the use of the tool **100**. As previously described with regard to the cleaning of the pipe **10**, the winch assembly **12** is mounted at one end of the pipe **10** and the winch assembly is mounted to the flange **16**. The winch is driven by a winch motor **14** and includes a winch spool **20** upon which is wound a wire line **18**, enough wire line to reach the entire length of the pipe **10**. The end of the wire line **18** terminates in a harness **146**, which couples to the tool **100** with a set of swivels **148**.

The transducer **140** provides a signal over the signal line **138** (which may be the same signal line **82** as previously described) to the computer **86** to provide a record of the corrosion mapping inspection. The signal line **82** is preferably taken up on the take-up reel **88** to keep the slack out of the signal line **82** during the inspection. As the wire line **18** is taken up by the winch, it passes through the encoder **90** as before. The encoder provides position of the tool **100** along the longitudinal direction of the main pipe **10**. The encoder **90** is coupled to the computer **86** by the signal line **92**. The encoder may alternatively be mounted to the carrier **100**, and the signal line **92** may then be included with the signal line **82**.

To use the tool **100**, the wire line **18** and the signal line **138** are fed through the length of the pipe **10**. The winch assembly **12** is then mounted to the flange **16** and the tool is hooked up to the signal line **138** and the connecting hose **128**. The tool **100** is placed flush with the end of the pipe **10**, and the encoder is zeroed. Water is then applied through the hose connection **128**, filling the annular chamber **135**. The winch motor is then turned on, pulling the tool **100** the entire length of the pipe **10** and the position of the tool **100** is known at all times from the encoder. The

transducer provides a measurement of wall thickness of the entire pipe **10**, which is recorder by the computer **86** for later review and analysis.

A similar arrangement is used for the corrosion mapping of the smaller tubulars, as shown in Figures 6a, 6b, 6c, and 6d. Referring first to Figures 6c and 6d, and preferred tool for corrosion mapping of the 3" and 4" tubulars are shown. A tool **150** is adapted for use in 4" nominal ID tubulars, and a tool **152** is adapted for use in 3" nominal ID tubulars. The tools contain the same components, which are numbers the same in Figures 6c and 6c. Thus, the following detailed description applied to both tools.

The tool (either **150** or **152**) comprises primarily a cylindrical body **154**, a left end cap **156**, and a right end cap **158**. A seal retaining ring **160** is mounted to the left end cap **156** with a set of bolts **162**, for example, and a seal retaining ring **164** is mounted to the right end cap **158** with a set of bolts **166**. for example. The seal retaining ring **160** holds a seal plate **168** in place, and similarly the seal retaining ring **164** holds a seal plate **170** in place. The seal retaining rings **160** and **164** are preferably secured to their respective retaining rings by a set of bolts **172**.

The right end cap **158** provides a mount for a nipple **174** and a hose connector **176**, providing a connection for the water source or hose connection **128**. When pressurized, water flows through the nipple **174** into a set of flow channels **178** to flood the chamber formed by the seal rings, the cylindrical body, and the wall of the tubular. This provides a signal couplant for the pulse echo for the corrosion mapping tool.

The left end cap **156** provides a mount for a two ring **180** to provide a means for pulling the tool through the tubular. The left end cap **156** includes penetrations **182** through which pass signal cables **184** to carry the ultrasonic test signal from the tool. The signal cables **184** terminate at transducers **186**, which are mounted in penetrations through the cylindrical body **154**. It should be understood that enough transducers are provided for a complete 360° coverage around the circumference of the tubular.

Figures 6a and 6b illustrate the use of the tool. The system of Figures 6a uses the same mounting for the winch as previously described, and the winch is rotatable on its mount so that the wire line **18** may be directed onto the tubular **34**. The tool **100** is drawn through the tubular **34** by the wire line, which passes over the encoder **90** so that the longitudinal position of the tool **100** is known at all times. The wire line passes over an idler pulley **98** which presses against the encoder **90**.

To use the corrosion mapping tool **100**, the wire line **18** and the signal cable **138** are fed down through the tubular **34** to the end, where the tool **100** is attached. The tool is then coupled to the wire line and signal cable, and the hose connection **128** is attached. The tool is registered with the end of the tubular, and the encoder is zeroed. With water pressure supplied by the hose connection **128** to provide a couplant for the transducers, the tool is drawn all the way through the tubular, measuring wall thickness and providing measurements to the computer.

Time of Flight Diffraction Inspection

The tool for performing Time of Flight Diffraction (TOFD) is not described in detail, because the tool may be acquired from ScanTech, 1212 Alpine Suite A, Longview Texas 75606. Further, the TOFD technology itself was adapted from techniques provided by AEA Technology plc, whose registered office is at 329 Harwell, Didcot, Oxfordshire OX11 0RA, United Kingdom. The technique will be described in sufficient detail for a complete understanding of the present invention.

In summary, the TOFD scanner system includes a very maneuverable crawler unit with four, large diameter rare earth magnetic wheels. The magnetic wheels grip the interior surface of the pipe **10** so that the crawler can be guided the entire length of the pipe. The crawler is remotely steered by the user, and the wheels include surface conforming suspension. The crawler is motor driven, and the motor is preferably a water shielded, high-torque, rare earth electric motor. All wiring, including control signals and inspection signal cables are shielded. The encoder, previously described, is preferably enclosed within the crawler for precise position

measurement and indication. The TOFD transducers are double-gimbaled for a full range of motion.

Figure 7 shows a crawler **200** carrying the TOFD system in operation. Two such crawlers **200** are shown in Figure 7, in order to show inspection of a longitudinal weld **202** and a girth weld **204**, while the system preferably includes a single crawler. The crawler preferably includes a single umbilical **206**, which includes a bi-directional signal cable **208** and a water supply line **210**. As previously described, the water supply line **210** provides the water couplant for the TOFD transducers. The signal cable **208** is preferably taken up on the take-up reel **88** to keep the slack out of the signal cable **208** during the inspection.

The signal cable includes a number of lines, including a video signal line **212** from the on-board camera to the television and video cassette recorder **84** and the computer **86** to provide real time viewing of the camera view and to provide a record of the inspection. The signal cable **208** further includes a signal line **214** from the encoder for precise position measurement and indication, a signal line **216** for carrying the TOFD signal to the computer, and a maneuvering control signal line **218** from a remote, joystick control **220**.

In operation, the crawler **200** is driven down the pipe, and the operator views the interior of the pipe at the television monitor **84**, controlling the movement of the crawler with the joystick control **220**. When a girth weld **204** is encountered, the crawler is turned and driven around the circumference of the pipe.

Figure 8a depicts the arrangement for the performance of TOFD testing in smaller tubulars in accordance with this invention. Figures 8b and 8c depict the tools of the invention for conducting TOFD testing in 4" and 3" nominal ID tubulars, respectively. The tools are identical, with the exception of an adapter sleeve **230** to adapt the tool to the larger 4" ID tubular. Thus, the following description will apply to both Figures 8b and 8c.

A TOFD tool **232** comprises a body **234**, a left end cover **236**, and a right end cover **238**. Within the body is a carrier and slide assembly **240**, which provides a

cam action for a set of yokes **242**. The yokes support a set of shoes **244** in which are mounted the TOFD transducers **246**. The shoes **244** are shown in Figures 8b and 8b in the deployed position in order for the shoes to make contact with the interior surface of the small tubular in preparation for the TOFD test. The carrier and slide assembly **240** is moved transversely by air pressure from an air cylinder **248** which is supplied from a nipple **250** and air connection **252**. Actuation or retraction of a rod **254** from the air cylinder moves the carrier and slide assembly **240** back and forth, so that the yokes ride up and down on the slides, deploying and retracting the shoes.

The body also retains a connector **256** for a water connection. The water from the water connection, as previously described, serves as a couplant for the TOFD signal. The body is firmly connected to a drive arm **258** which provides a means for rotating the tool **232** in a rotary motion for complete circumferential coverage of the TOFD test. The drive arm **258** is preferably connected to a square tube drive means **260** (Figure 8a) by removable screws **262**. At the opposite end of the body is a signal cable connector **264** for connecting the tool to the computer, preferably by way of a pre-amplifier **266** (Figure 8a). At the same end of the body is an eyebolt connection **268** for pulling the tool through the tubular.

Figure 8a shows the use of the tool **232** in a small diameter tubular in performing the TOFD test. As previously described with regard to the use of other tools, the wire line **18** is coupled to the eyebolt **268** and then back to the winch assembly **12** driven by a winch motor **14** and the winch assembly **12** is adapted for mounting to the flange **16**. The wire line **18** is pulled over an idler pulley **98** which contacts the encoder **90** to precisely locate the tool **232** within the tubular. The signal cable **264** is wound to a takeup reel **88** to keep slack out of the cable. At the other end of the tubular are provided the drive means **260**, a water supply connection **270** for the water couplant, and an air supply connection **272** for coupling to the connection **252** (Figures 8b and 8c).

To use the tool **232**, the signal line **264** and the wire line **18** are fed through the tubular and connected to the tool. The air and water connections are made up,

and rotating drive means **260** is connected. Then, the tool is registered with the end of the tubular, and the encoder is zeroed. The tool is the pulled through the tubular and rotated by the rotating drive means **260**, imaging the tubular for internal flaws. The computer captures the image for later review and analysis.

The principles, preferred embodiment, and mode of operation of the present invention have been described in the foregoing specification. This invention is not to be construed as limited to the particular forms disclosed, since these are regarded as illustrative rather than restrictive. Moreover, variations and changes may be made by those skilled in the art without departing from the spirit of the invention.

We claim:

1. A method of inspecting a pipe comprising the steps of:

a. visually inspecting the inside of a pipe with a camera;

b. determining wall thickness of the pipe with a corrosion mapping tool from inside the pipe; and

c. inspecting the pipe for flaws with a time of flight diffraction tool from inside the pipe.

2. The method of claim 1, further comprising the step of cleaning the inside of the pipe prior to inspecting the inside of the pipe with a camera.

3. The method of claim 2, wherein the step of cleaning the inside of the pipe includes grinding the inside of the pipe to remove weld material that extends into the pipe to a point inside the nominal ID of the pipe.

4. The method of claim 1, further comprising the steps of:

a. prior to the step of visually inspecting the inside of a pipe, coupling the camera to a drawing system;

b. prior to the step of determining wall thickness of the pipe with the corrosion mapping tool from inside the pipe, coupling the corrosion mapping tool to the same drawing system as in step a.; and

c. prior to the step of inspecting the pipe for flaws with the time of flight diffraction tool from inside the pipe, coupling the time of flight diffraction tool to the same drawing system as in step a.

5. A system for inspecting a tubular comprising:

a. an inspection tool; and

b. a drawing system coupled to the inspection tool with a wire line, the drawing system adapted to pull the inspection tool through the tubular.

6. The system of claim 5, further comprising a decoder to locate the position of the inspection tool within the tubular.

7. The system of claim 5, wherein the inspection tool comprises a visual inspection tool including a camera for visual inspection of the interior of the tubular.

8. The system of claim 5, wherein the tool comprises a corrosion mapping tool.

9. The system of claim 5, wherein the tool comprises a time of flight diffraction inspection tool.

10. The system of claim 5, further comprising a cleaning tool adapted to be removably coupled to the drawing system.

11. The system of claim 5, wherein the tool is selected from the group consisting of a corrosion mapping tool and a time of flight diffraction tool, each of which is adapted to the coupled to the same drawing system.

12. The system of claim 10, wherein the cleaning tool comprises:

a. a wire brush;

b. a centralizer ring adjacent the wire brush;

c. a drive motor for driving the wire brush in a radial direction; and

d. a drive arm coupled to the wire brush, the centralizer ring, and the drive motor.

13. The system of claim 12, wherein the drive arm comprises a plurality of sections adapted to be coupled together.

14. The system of claim 12, wherein the cleaning tool further comprises:

a. a mount on which the drive motor is mounted; and

b. at least two guide bars which slidingly extend into auxiliary lines adjacent the pipe.

15. The system of claim 10, further comprising a rotary cutter adjacent the wire brush.

16. The system of claim 7, wherein the visual inspection tool comprises:

a. a camera carrier to hold the camera, the camera carrier adapted to be coupled to the wireline;

b. a plurality of spring loaded wheels to retain the carrier inside the tubular; and

c. a signal line to couple the camera to a monitor.

17. The system of claim 7, wherein the visual inspection tool comprises:

a. a centralizer sleeve adapted to couple the camera to the wireline; and

b. a signal line to couple the camera to a monitor.

18. The system of claim 8, wherein the corrosion mapping tool comprises:

a. a substantially cylindrical body defining mutually opposed ends;

b. a flange on each of the ends of the body;

c. a substantially circular seal plate on each flange; and

d. a pulse echo transducer on the body.

19. The system of claim 18, further comprising a hub on the end plate, the hub including a coupling adapted to receive a water hose connection.

20. The system of claim 19, further comprising:

a. a water channel in the hub terminating at the coupling;

b. a flexible tube in fluid communication with the water channel; and

c. a penetration through the body; wherein the flexible tube is in fluid communication with the penetration, and wherein the water channel, the flexible tube, and the penetration carry water to flood an annular chamber formed by the body, the seal plates, and the interior diameter of the tubular.

21. The system of claim 18, further comprising:

a. a cable connector on one of the flanges to receive a signal from the transducer;

b. a signal cable to connect the cable connector to a computer exterior the tubular.

22. The system of claim 9, wherein the time of flight diffraction tool comprises:

a. a body;

b. a left end cover;

c. a right end cover;

d. carrier and slide assembly within the body between the left and right end covers, the carrier and slide assembly including a cam surface;

e. a set of yokes riding on and actuated by the cam surface; and

f. a set of shoes, each shoes having a transducer mounted therein.

23. The system of claim 22, further comprising a pneumatic actuator coupled to the carrier and slide assembly for linear movement of the cam surface.

24. The system of claim 22, further comprising a penetation through the right end cover to receive a water couplant connection.

25. A time of flight diffraction tool comprising:

a. a self-powered, remotely operable crawler having a plurality of magnetic wheels capable of holding the crawler in contact with the interior surface of a tubular;

b. a time of flight diffraction transducer and receiver on the crawler; and

c. an umbilical coupling the time of flight diffraction transducer and receiver to a remote monitor.

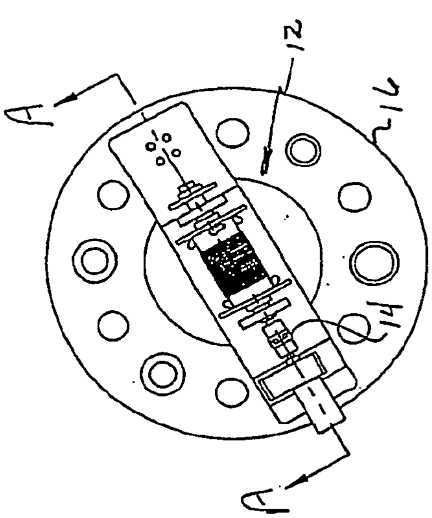
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Fig 1b

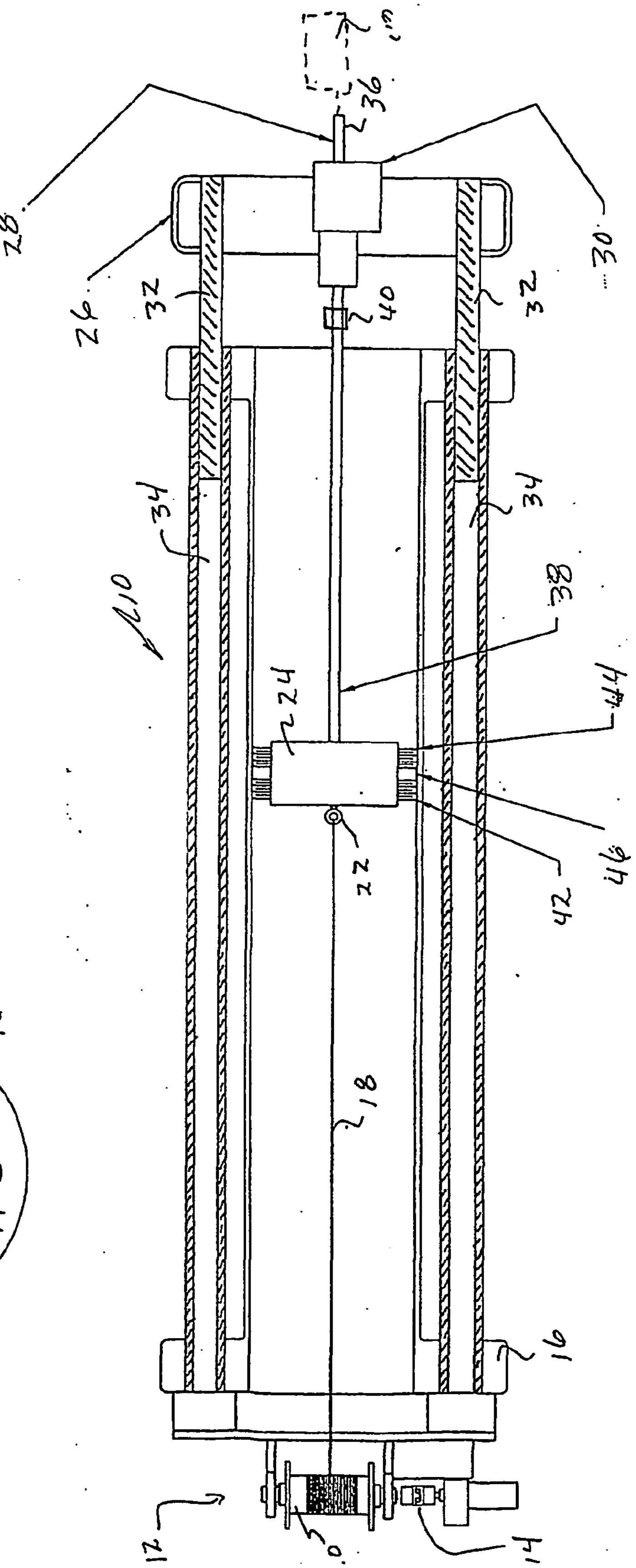
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Fig 1a

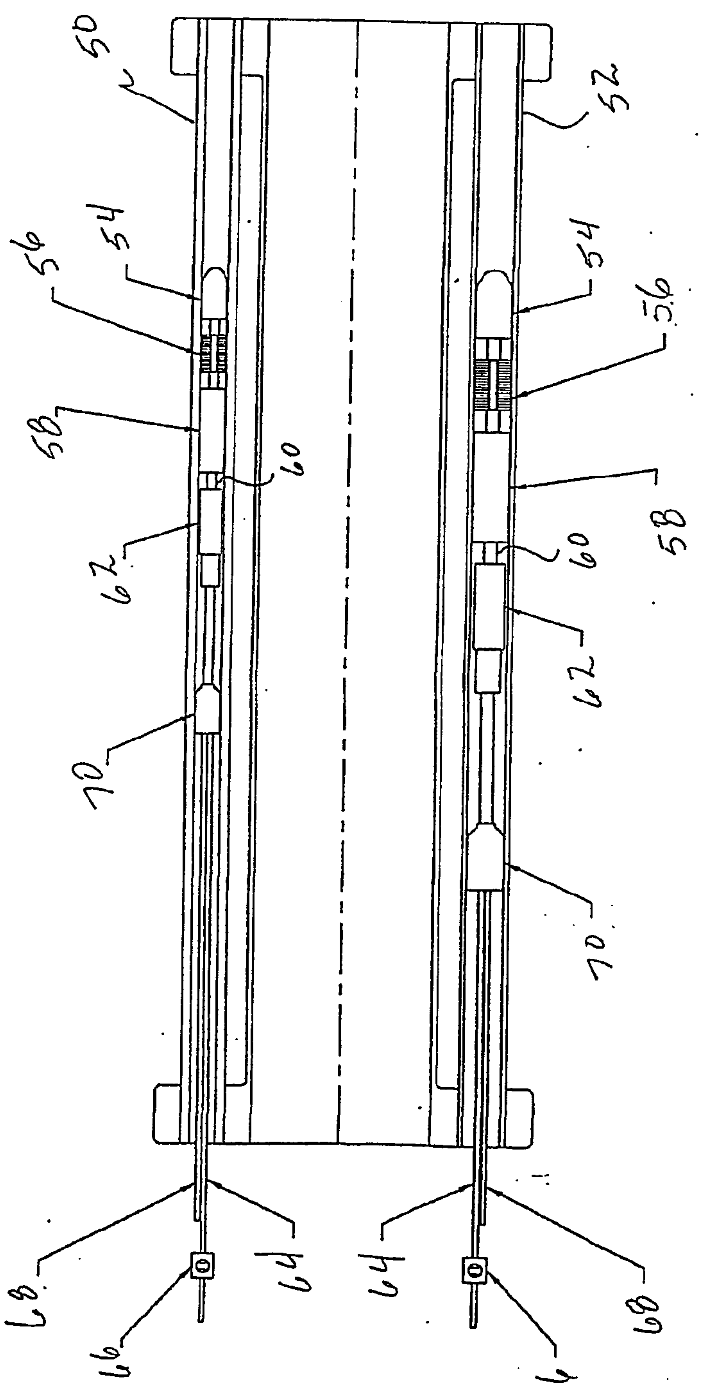
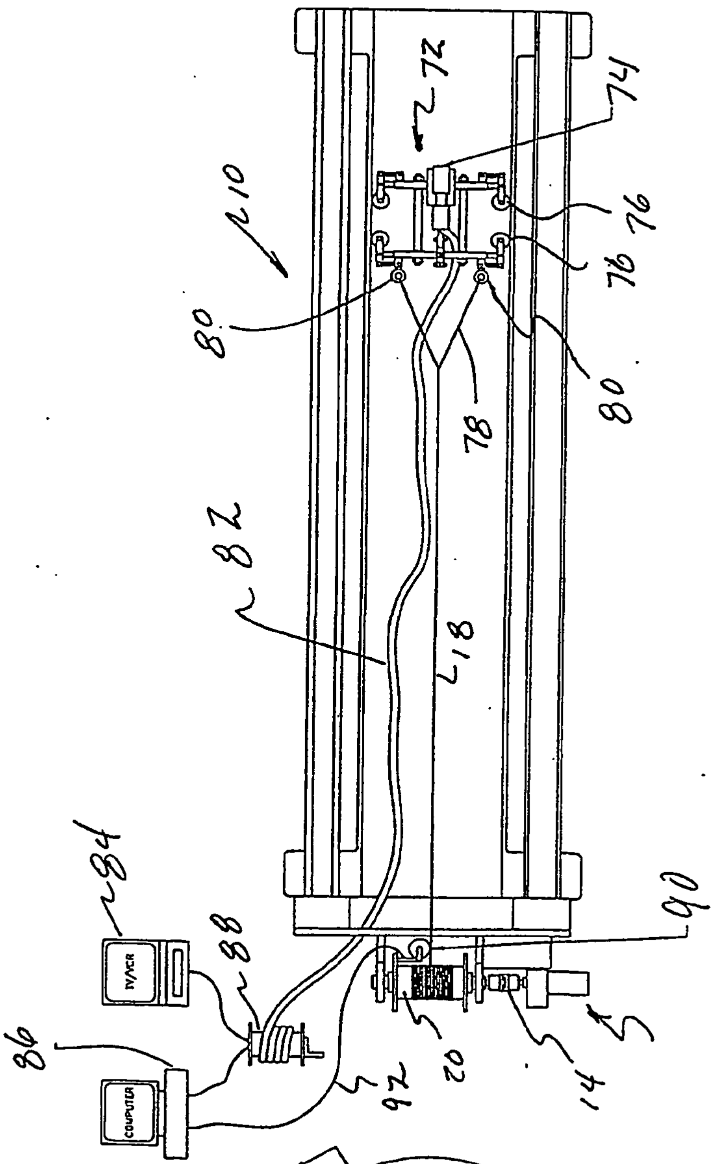


Fig 2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COMPUTER
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Fig. 3a

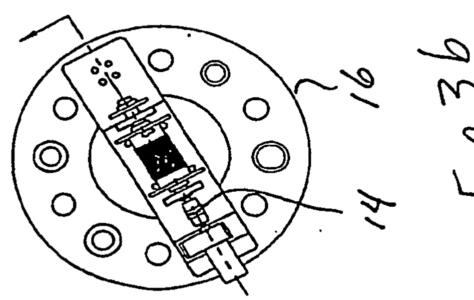
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Fig 3b

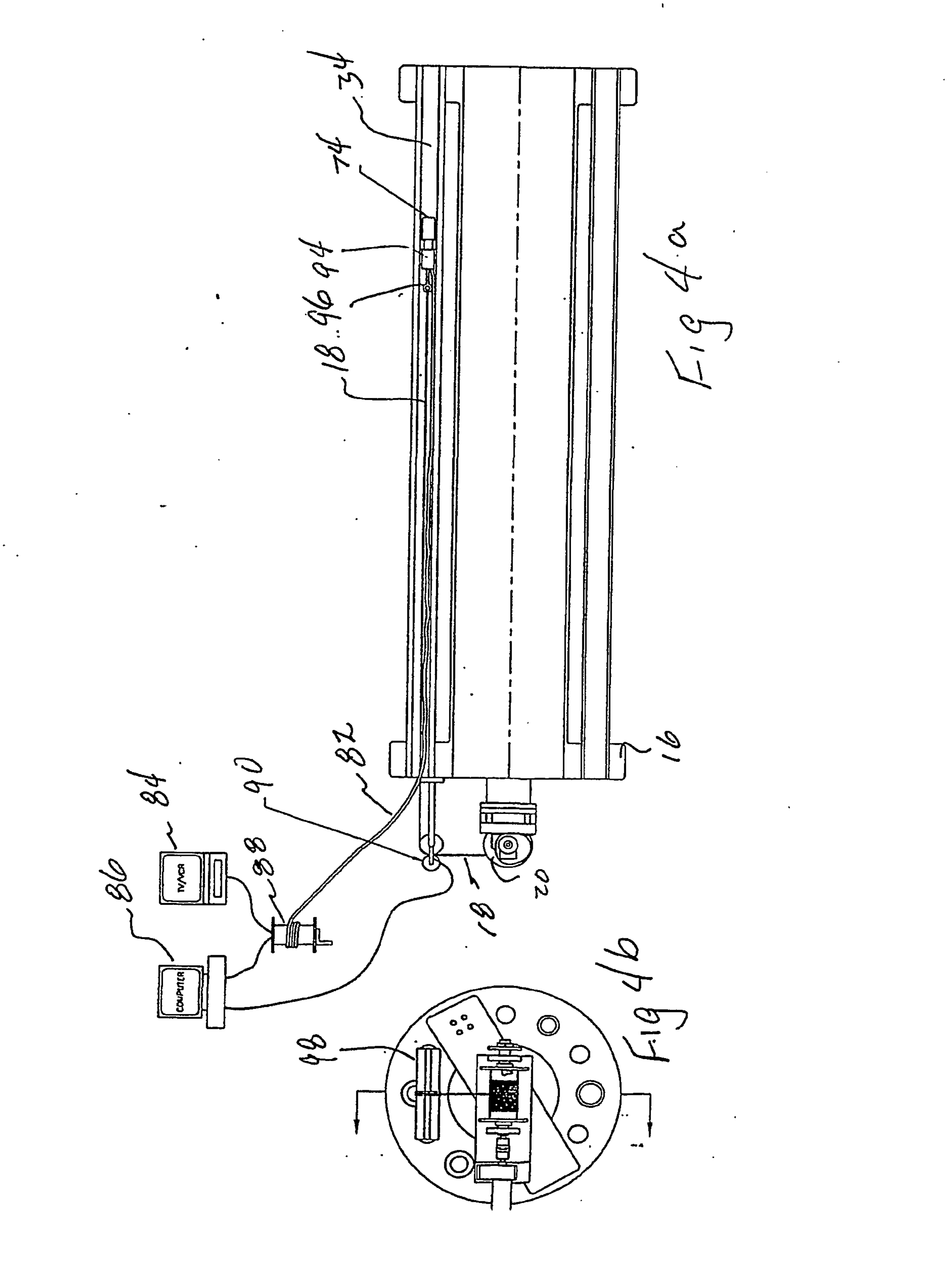

Fig 4a

Fig 4b

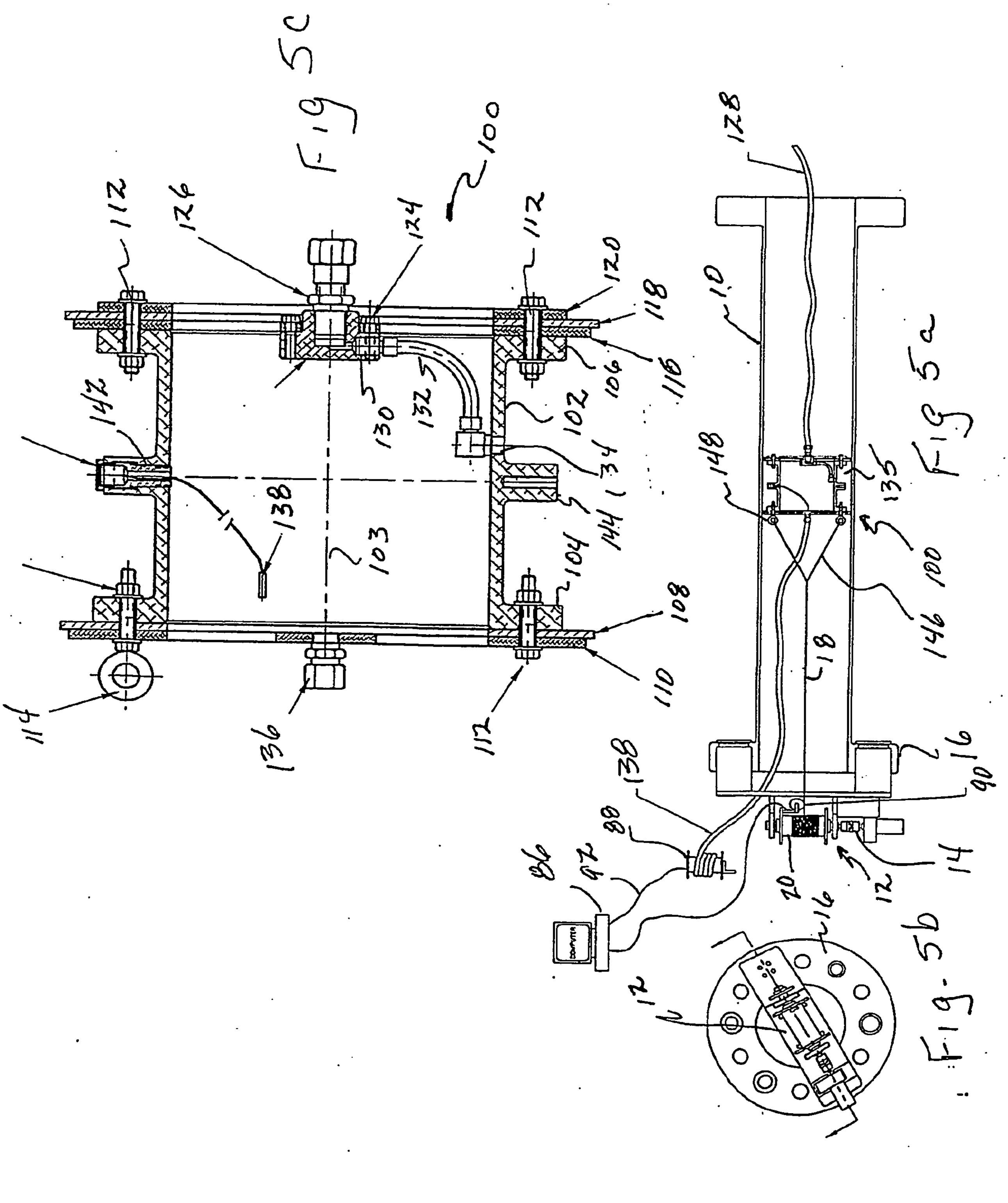

Fig 5c

Fig 5a

Fig 5b

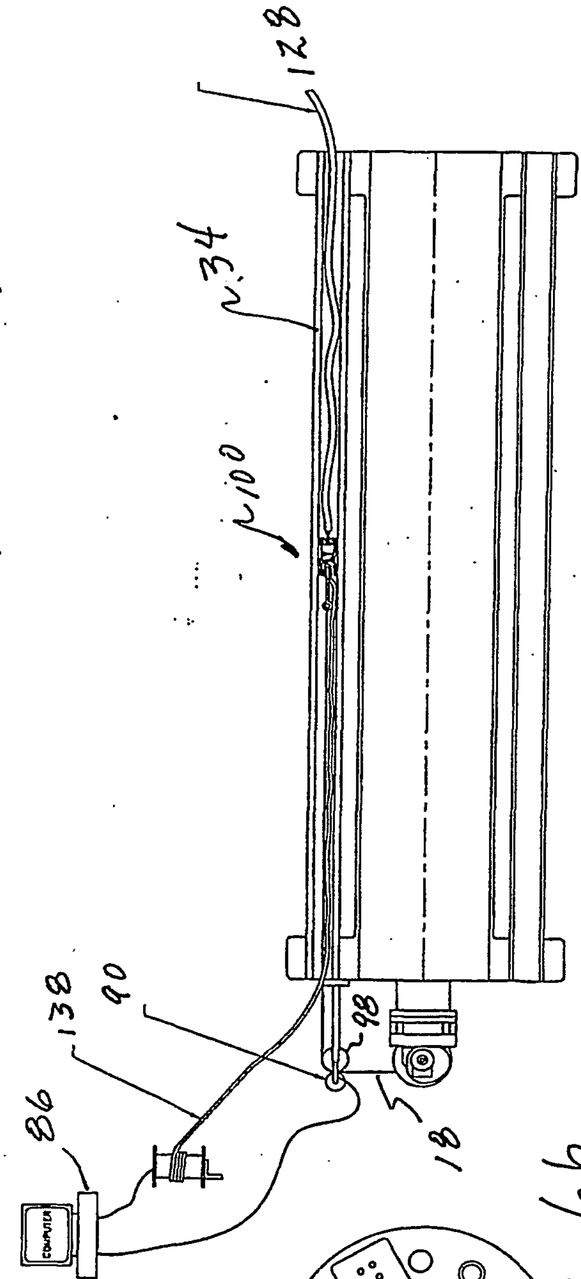

Fig 6a

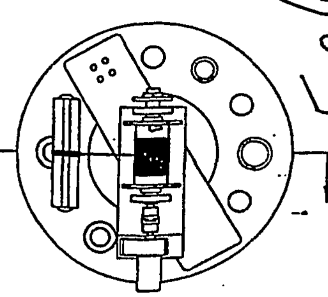

Fig 6b

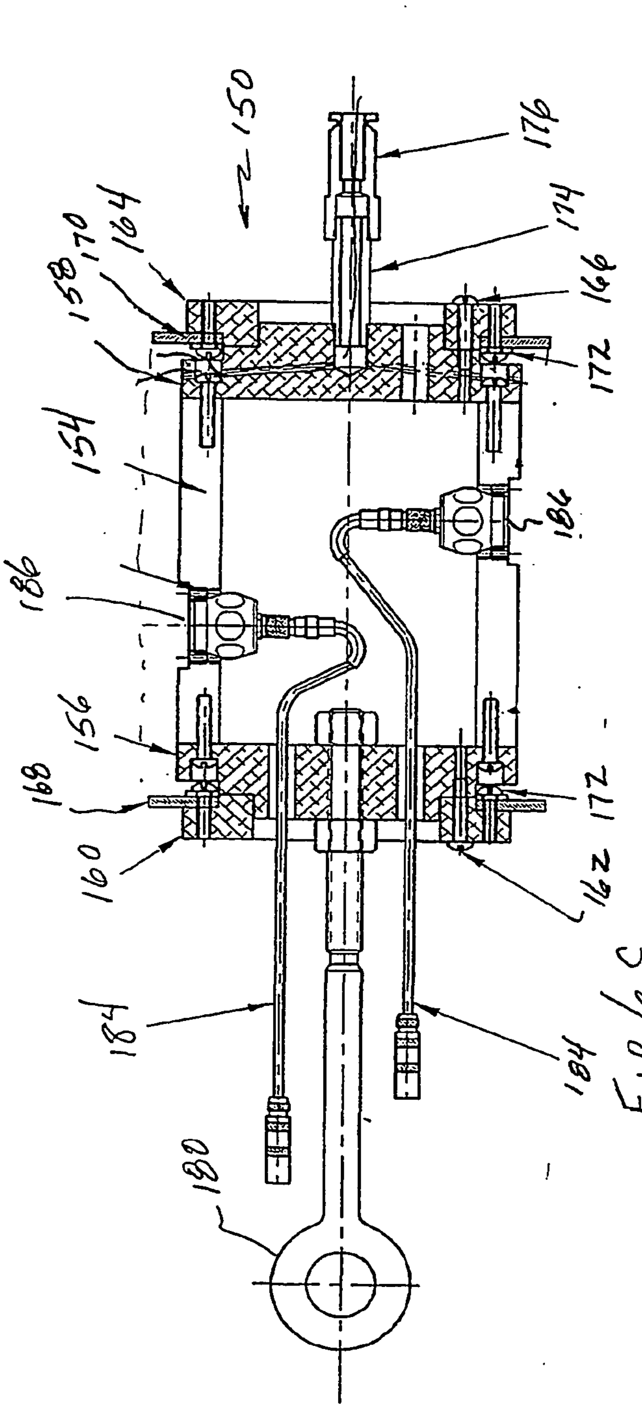
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Fig 6c

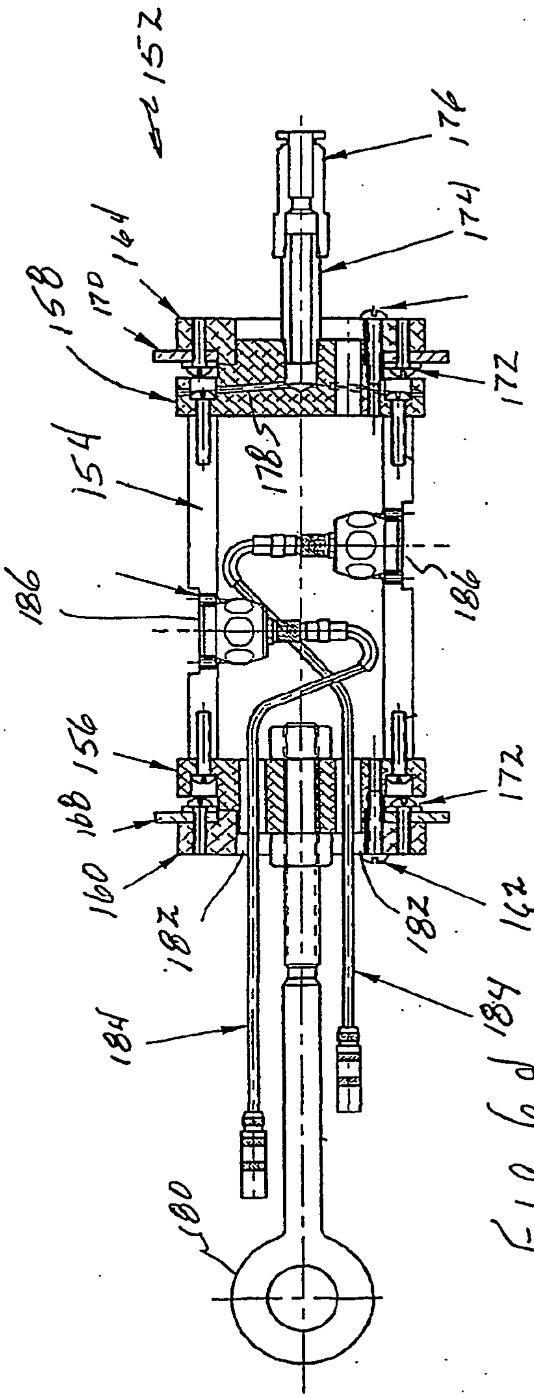
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Fig 6d

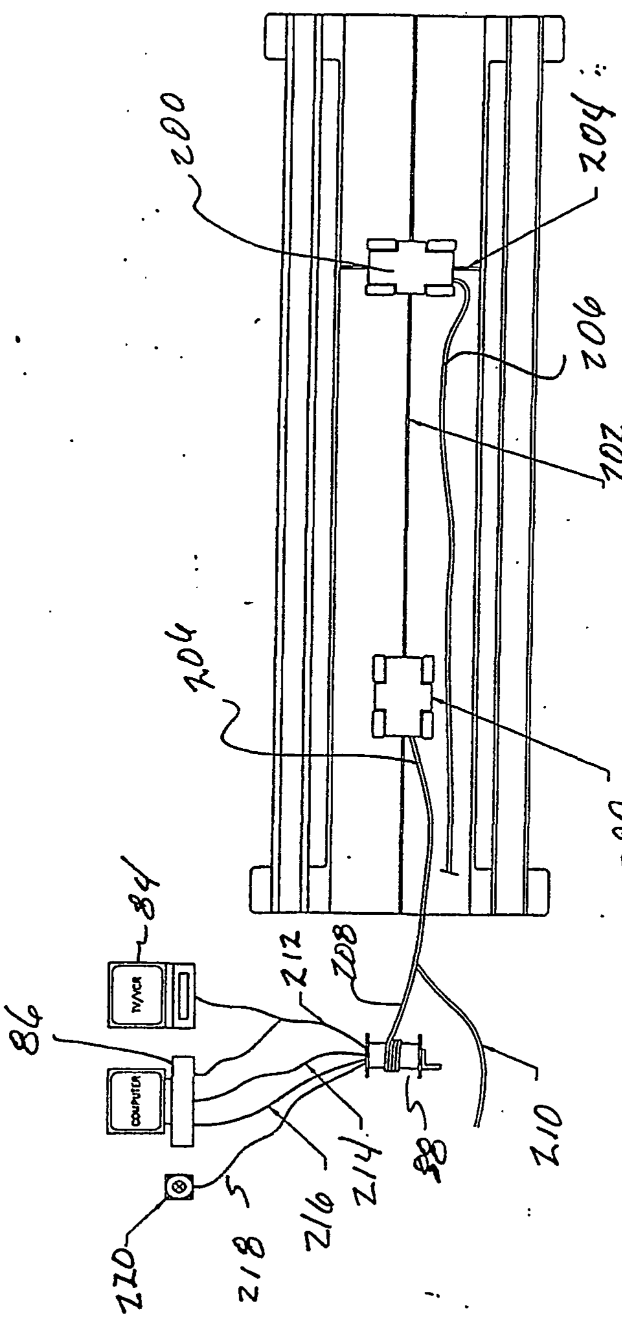
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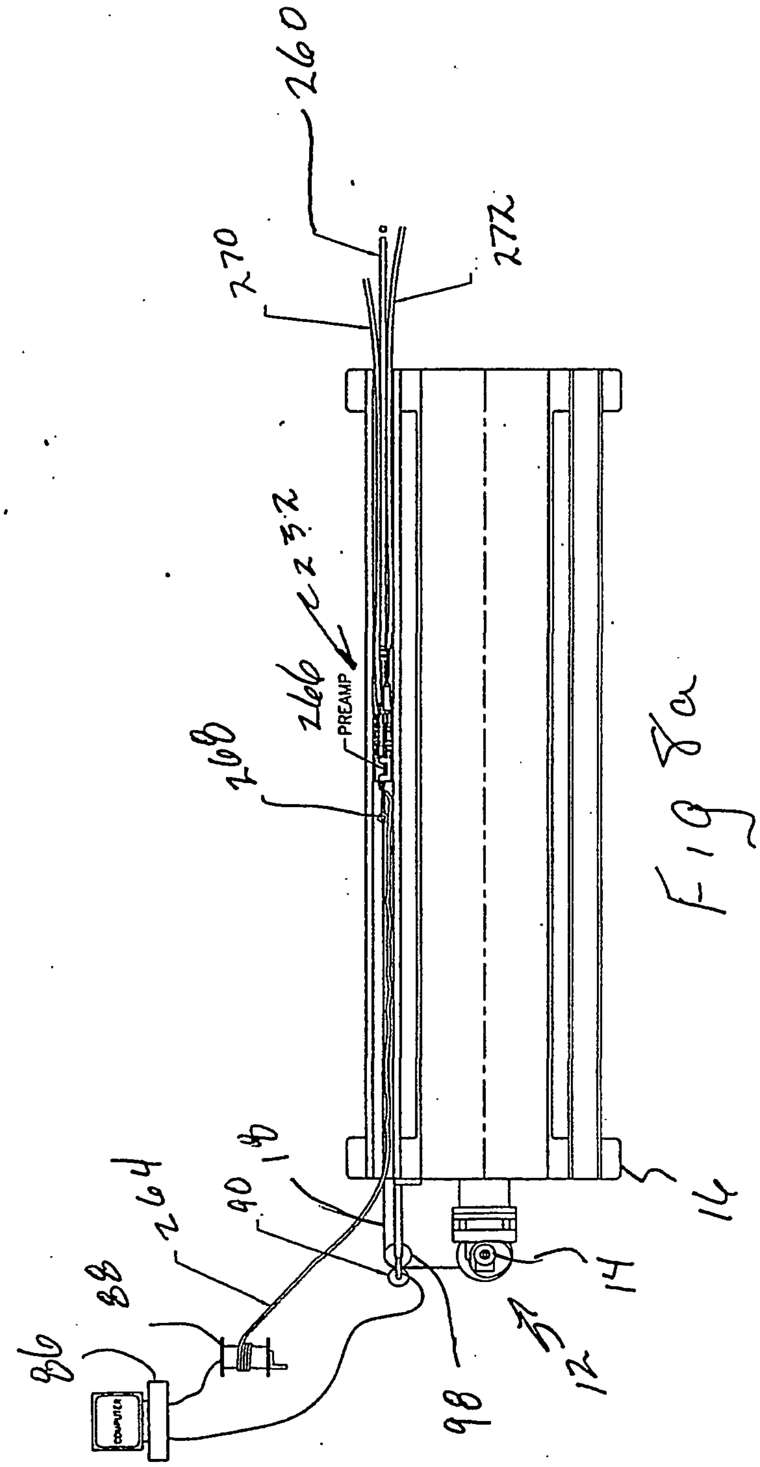
Fig 7


260
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COMPUTER
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Fig 8a

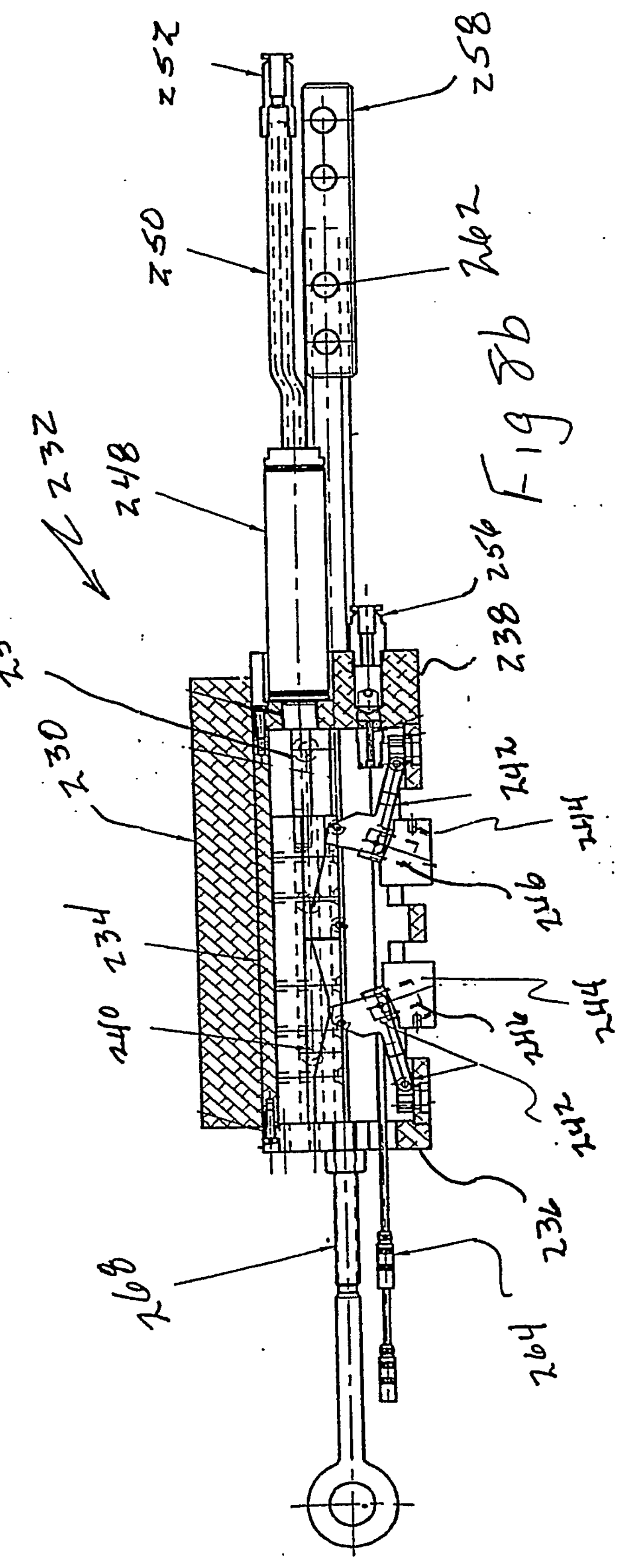
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Fig 8b

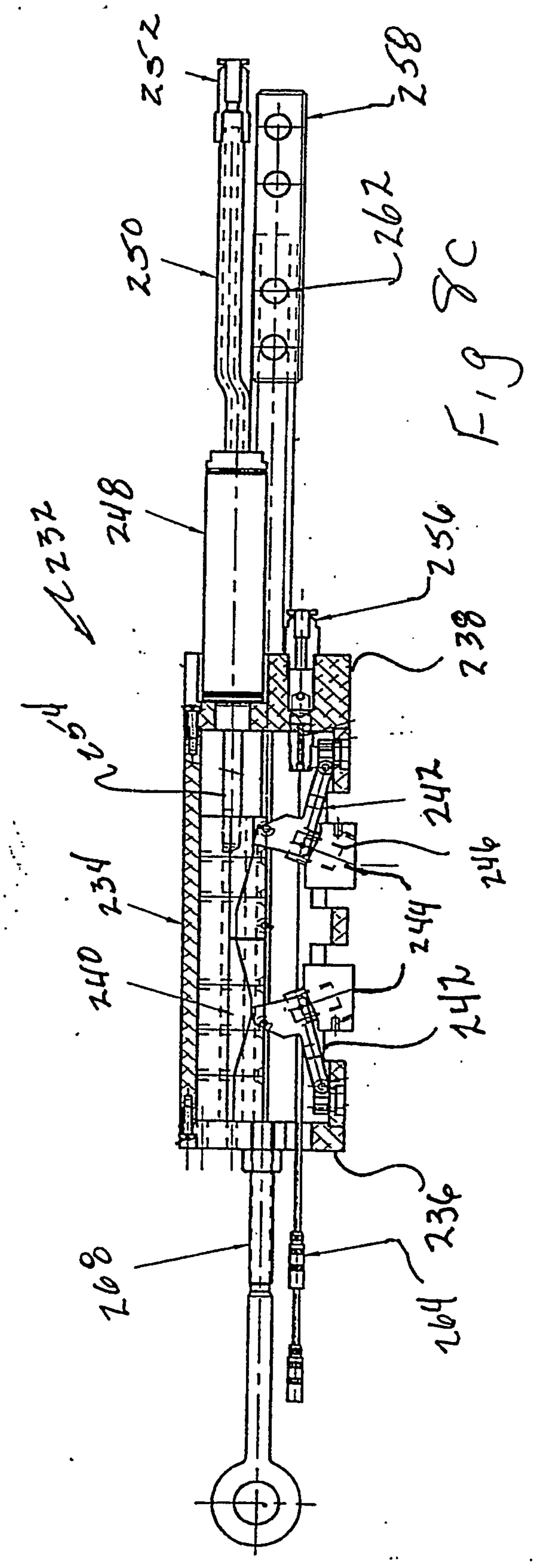
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Fig 8c

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(30) Priority Data:
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(71) Applicant: COOPER CAMERON CORPORATION [US/US]; 515 Post Oak Boulevard, Suite 1200, Houston, TX 77027 (US).

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(74) Agent: COOK, Tim; Browing Bushman P.C., 5718 Westheimer, Suite 1800, Houston, TX 77057 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
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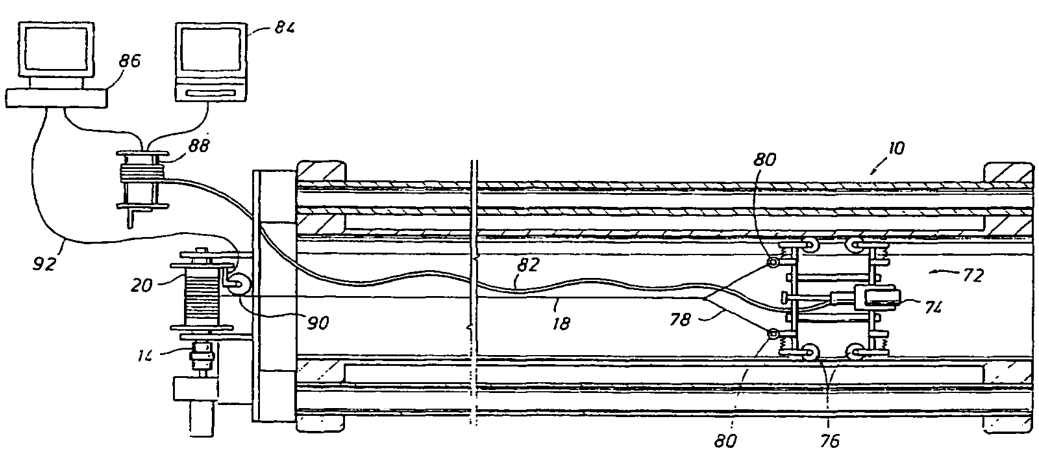
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ULTRASONIC TESTING SYSTEM FOR TUBULARS



(57) Abstract: A comprehensive system for the cleaning, inspection, and testing of tubulars, particularly riser pipes, is provided. In a first aspect, a method of inspecting a tubular comprises cleaning, visually inspecting, corrosion mapping, and TOFD testing the tubular. In another aspect, a specially designed or adapted tool is provided for each of the steps of the method.

WO 02/044709 A3

INTERNATIONAL SEARCH REPORT

International Application No
/US 01/51194

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B08B9/04 G01N29/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B08B G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 736 722 A (BRITISH GAS PLC) 9 October 1996 (1996-10-09)	5
A	abstract; figure 2 column 1, line 6 -column 3, line 45 ---	1-4,9, 11,22-25
X	DE 198 37 032 A (ROHRABSPERRUNGEN UND HANDELSGE) 17 February 2000 (2000-02-17)	5
A	column 1, line 33 - line 42 ---	1-4
X	FR 2 667 519 A (INSPECTRONIC) 10 April 1992 (1992-04-10)	5
Y	abstract; claim 1; figure 1	9,11
A	column 1, line 1 -column 7, line 29 --- -/--	1-4, 22-25

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

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Date of the actual completion of the international search	Date of mailing of the international search report
4 March 2003	05.06.03

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Uttenthaler, E

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	VAN AGTHOVEN R ET AL: "Ultrasonic inspection of risers: A simple and affordable alternative to self-contained pigging" PIPES PIPELINES INT;PIPES AND PIPELINES INTERNATIONAL SEPTEMBER/OCTOBER 2001, vol. 46, no. 5, September 2001 (2001-09), pages 37-44, XP009006658	1-4
A	the whole document	5,9,11, 22-25

Y	WO 95 03526 A (COMMW SCIENT IND RES ORG ;MELBOURNE WATER CORP (AU); MACINTYRE IAN) 2 February 1995 (1995-02-02)	1-4
A	abstract; figures 1,2	5,9,11, 22-25
	page 4, line 7 -page 20, line 11; table 1	

Y	US 5 473 953 A (APPEL D KEITH) 12 December 1995 (1995-12-12)	25
A	abstract; figure 1 column 1, line 7 - line 60	1-5

Y	BERNARD LARRY: "TIME-OF-FLIGHT DIFFRACTION TECHNOLOGY FOR ULTRASONIC INSPECTION OF PIPING AND PRESSURE-RETAINING COMPONENTS" MATER EVAL MAY 1987, vol. 45, no. 5, May 1987 (1987-05), pages 506-507, XP009006626	1-4,9, 11,25
A	the whole document	5,22-24

A	DE RAAD J A ET AL: "Mechanized ultrasonic testing on girth welds during pipeline construction" MATER EVAL;MATERIALS EVALUATION AUG 1997 AMERICAN SOC FOR NONDESTRUCTIVE TESTING, COLUMBUS, OH, USA, vol. 55, no. 8, August 1997 (1997-08), pages 890-895, XP009006892 the whole document	1-4,9, 11,22-25

A	LILLEY J ET AL: "In-line inspection using time-of-flight diffraction" WELD MET FABR;WELDING AND METAL FABRICATION OCT 1991, vol. 59, no. 8, October 1991 (1991-10), XP009006661 the whole document	1-4,9, 11,22-25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 01/51194

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-5, 9, 11, 22-25

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-4, 5(part), 9, 11, 22-25

   Apparatus and method for inspecting tubulars from the inside involving the time of flight diffraction technique.

2. Claims: 1 (part), 5(part), 7, 16, 17

   Camera mounting and connecting on a tool for the visual inside inspection of a tubular, the tool being drawn through the tubular.

3. Claims: 1(part), 5(part), 6, 8, 11(part), 18-21

   Corrosion mapping tool mounted on a tool for the inside inspection of a tubular, the tool being drawn through the tubular.

4. Claims: 1(part), 5(part), 10, 12-15

   Cleaning tool removably mounted on a drawing system for the inside cleaning of a tubular, the cleaning tool being drawn through the tubular.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/51194

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0736722 A	09-10-1996	GB 2301646 A	11-12-1996
		DE 69601434 D	11-03-1999
		DE 69601434 T	22-07-1999
		ES 2127605 T	16-04-1999
DE 19837032 A	17-02-2000	NONE	
FR 2667519 A	10-04-1992	NONE	
WO 9503526 A	02-02-1995	AU 7259994 A	20-02-1995
		EP 0710351 A	08-05-1996
		ZA 9405334 A	28-02-1995
US 5473953 A	12-12-1995	NONE	